

**REPORT DOCUMENTATION PAGE**

AFRL-SR-AR-TR-07-0009

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<b>1. REPORT DATE (DD-MM-YYYY)</b> September 22, 2006		<b>2. REPORT TYPE</b> Final		<b>3. DATES COVERED (From - To)</b> July 1, 2005 – November 30, 2005	
<b>4. TITLE AND SUBTITLE</b> Superconducting Magnet System for a Low Temperature Laser Scanning Microscope				<b>5a. CONTRACT NUMBER</b>	
				<b>5b. GRANT NUMBER</b> FA9550-05-1-0425	
				<b>5c. PROGRAM ELEMENT NUMBER</b>	
<b>6. AUTHOR(S)</b>  David C Larbalestier				<b>5d. PROJECT NUMBER</b>	
				<b>5e. TASK NUMBER</b>	
				<b>5f. WORK UNIT NUMBER</b>	
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  Applied Superconductivity Center University of Wisconsin –Madison  1500 Engineering Drive Room 909 ERB Madison WI 53706-1609				<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>	
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> AFOSR/NE 801 N. Randolph St. Room 732 Arlington VA 22203-1977 (Attn: Dr Harold Weinstock)				<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> AFOSR	
				<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>	
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b>  <i>Distribution Statement A: Unlimited</i>					
<b>13. SUPPLEMENTARY NOTES</b>					
<b>14. ABSTRACT</b> The dominant current-limiting mechanism in YBCO CC tapes still occurs at grain boundaries over a wide range of magnetic fields, even when the FWHM of the texture distribution is only 4-5°. The LTLSM is one of very few instruments that can directly observe this limitation. Our initial studies with the LTLSM bought with this equipment grant show that the intragrain critical current density crosses over with the intergrain critical current density at fields of about 2T near liquid nitrogen temperature. The local transport current distribution and the E(x,y) distribution depend quite strongly on magnetic field. The LTLSM provides a unique capability for studying this subject because it can operate in any magnetic field. Our aim here was to incorporate a 5T superconducting magnet/cryostat into our LTLSM system and to be able to measure the magnetic field dependencies of the voltage change response distributions. The system was installed and worked very well, providing direct data on the influence of grain boundaries and other local sources of dissipation.					
<b>15. SUBJECT TERMS</b>					
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b> David C Larbalestier
<b>a. REPORT</b>	<b>b. ABSTRACT</b>	<b>c. THIS PAGE</b>			<b>19b. TELEPHONE NUMBER (include area code)</b> (608) 263 2194

# Superconducting Magnet System for a Low Temperature Laser Scanning Microscope (LTLSTM)

AFOSR Grant FA9550-05-1-0425  
Final Report

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## SYNOPSIS

This AFOSR grant allowed the purchase of the following equipment:

- 5 tesla Microstat BT Magnet/cryostat, Transfer tube & storage vessel top from Oxford Instrument Company (assembled);
- Continuous flow cryostat with calibrated Cernox resistance thermometer & helium transfer tube from Janis Research Company, Inc (not assembled).
- Gated Integrator and Boxcar averager, preamplifier, gate scanner, sampler and mainframe with display and power supply from Stanford Research Company.

## SUMMARY OF WORK COMPLETED

To study the magnetic field dependence of the local dissipation we incorporated the 5T Microstat BT cryostat/magnet from Oxford Instruments into our existing LTLSTM system. For our first in-field measurements we used two bath-type cryostats: one for housing the sample and another for housing the superconducting magnet for generating the external magnetic field. The optical components of the microscope were placed outside the two cryostats (see Fig.1).

To observe the capabilities of the LTLSTM, we measured a coated conductor link of about  $368 \text{ } \mu\text{m} \times 156 \text{ } \mu\text{m}$ , which was cut by high power laser from OX210 MOD YBCO CC on RABITS film from AMSC; the YBCO is  $0.8 \text{ } \mu\text{m}$  thick. The sample was varnished to a copper cold finger and placed in vacuum in a nitrogen-filled optical cryostat. All in-field measurements were done at 82 K. Temperature was stabilized actively with a precision of  $10^{-3} \text{ K}$  to provide stability during the 0.5 – 2.5 hours long scans.

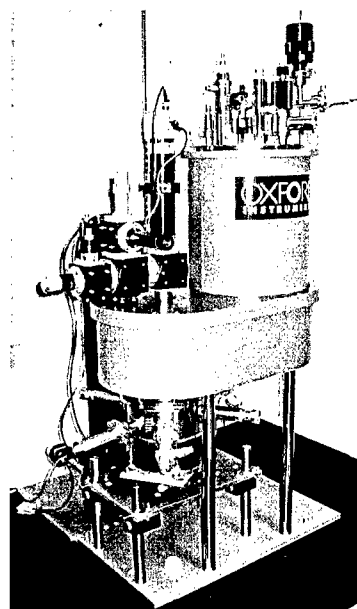


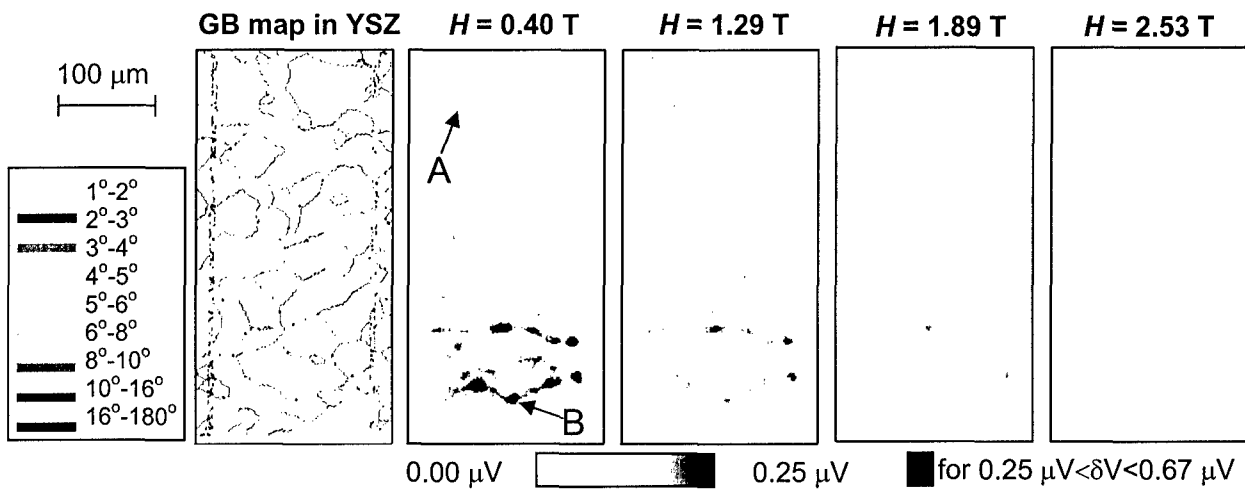
Fig.1. the LTLSTM setup.

The YBCO critical temperature is 90 K, as defined as defined by the curvature change in the  $R(T)$  dependence under an ac-transport current of 10 uA (peak to peak) in the LTLSTM. We detected by transport measurements the self-field critical current  $J_c$  of about  $0.5 \text{ MA/cm}^2$  at 82 K for the link, which was used for visualization. All in-field measurements were done at 82 K in the persistent mode of the superconducting magnet. The magnetic field in range of 0 T – 2.5 T was applied perpendicular to the sample plane.

To be able to compare  $dV$  maps we kept constant the average electric field by adjusting the bias current for each magnetic field. A characteristic set of voltage responses measured at the same average electric field (50 uV) and the same laser beam power are shown in Fig.2. Both the spatial and  $dV$  amplitude scales are the same.

The large average voltage was chosen to ensure proper signal to noise ratio at the high magnetic fields, however it did not allow us to visualize self field  $dV$  due to risk of burning out the sample. (The self field  $dV$  was measured at 10 uV: not shown) Black areas in Fig.2 correspond to regions where the dissipation is higher. To enhance the contrast of  $dV$  images at high magnetic fields, the  $dV$  signal maximum is scaled to about 1/3 of the maximum value of  $dV$  measured at lowest field.

After the low temperature experiment was finished, the YBCO layer was removed (using 1% nitric acid in water in an ultrasonic bath for 30 sec) so as to reveal the underlying YSZ buffer layer. An EBSD GB misorientation map (shown at the left side of Fig. 2) of the YSZ buffer layer was measured using Orientation Imaging Microscopy. Since the YBCO crystal orientation is basically repeating the YSZ crystal orientation, we use our EBSD data on the YSZ for understanding the behavior of the YBCO layer. By comparing LTLSTM and EBSD data we noticed, that at low fields the dissipation is crowded near high angle GBs areas as we observed before.

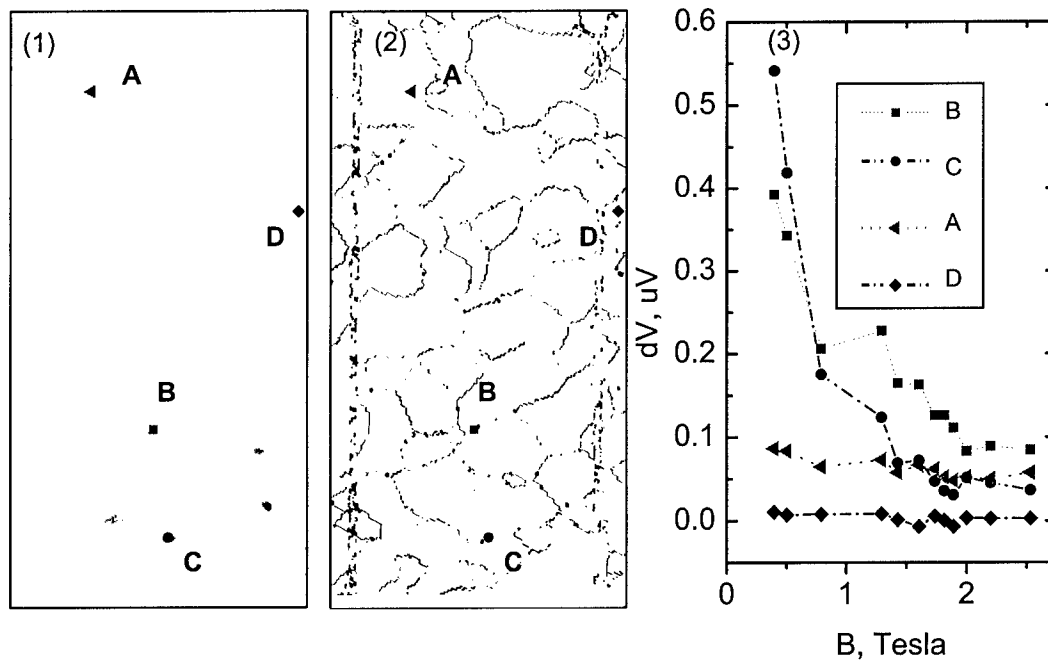


**Fig. 2: LTLSTM data set. Comparison of GB misorientation map in YSZ and set of voltage responses obtained in MOD YBCO CC on RABITS link at the same average voltage of about 50 uV. The bias current was of course varying with magnetic field. All data was measured at  $T=82 \text{ K}$ . The magnetic field direction is perpendicular to the sample plane and the macroscopic bias current direction is vertical.**

The maps in Fig. 2 clearly show that the dissipation becomes much more homogeneous as  $H$  increases and that some GBs do not produce any inhomogeneous local dissipation (for example

area “B” in fig. 2). The signal to noise ratio in the dV map dropped. Therefore at high field we used comparatively long averaging time 0.3 sec per point instead of 0.03 sec at low field. We observed by the LTLSM for the first time that the low amplitude local dissipation nearby some GBs weakly depends on the magnetic field (Fig. 3: LTLSM area “A”). Using the LTLSM we observed a smooth transition from GB current limited regime with sharp GB features on dV maps to the almost bulk limited regime with the maximum dV amplitude reduced and spread out over the link in CC on RABiTS. We did not observe any sharp transitions of dissipation at any magnetic field applied. Compared to previously measured temperature dependencies of the dV maps, we noticed that the patterns of the dV maps evolve similarly with magnetic field and temperature: GB features became less pronounced and the dV signal spreads out over the link.

To analyze dissipation maps in detail we plotted in Fig.3 the magnetic field dependencies of the dV signal in some characteristic points. We observed that the slope of the local dV(H) is different for different GBs.

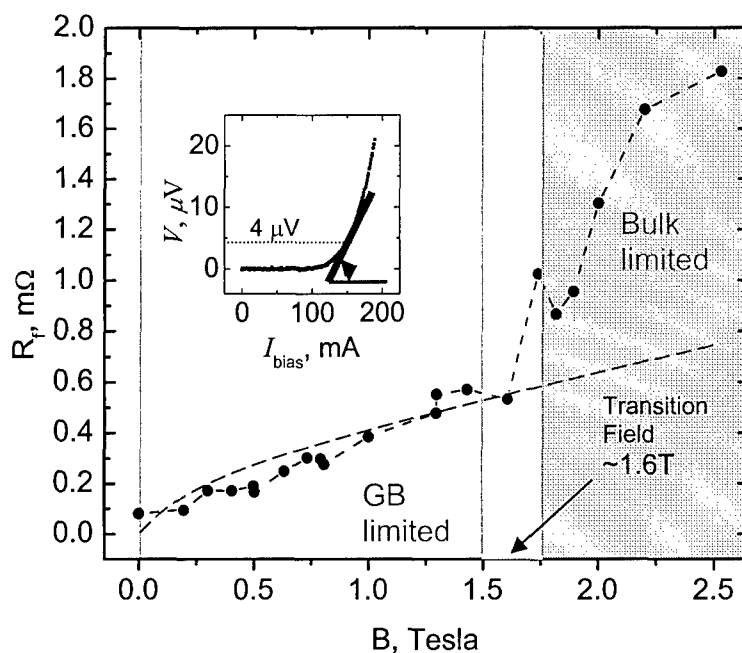


**Fig. 3: (1) dV response map, measured at 0.4 Tesla, 82K; (2) EBSD map of YSZ layer plotted at the same spatial scale as (1) with the same correspondence of misorientation angles and colors as in Fig.2. (3) Field dependence of dissipation in characteristic points.**

To find the independently the transition field from current voltage characteristics the flux-flow resistance ( $R_f$ ) was calculated at  $V = 4$  mV. For the the GB  $J_c$  limited regime the magnetic field dependence of the  $R_f$  has a form [A.Gurevich, et al., *PRL* 097001-1, 88 (2002)]:

$$R_f = \frac{R\sqrt{H}}{\sqrt{H + H_0}} \quad (1).$$

For the bulk  $J_c$  limited regime the  $R_f$  is growing faster then in Eq.1. Therefore it is easy to estimate the transition field, which was in our case  $\sim 1.6$  T (Fig.3).



**Fig.4. The magnetic field dependence of the flux-flow resistance.**

We detected the weakening of grain boundary effects on local electric field in RABiTS CC as the magnetic field is raised. We observed that magnetic field dependence of local dissipation is non-uniform and depends on GB misorientation angles. We observed that the dependencies  $dV(T)$  and  $dV(H)$  appears similar.

In summary, the 5T magnet system for the LTLSM was installed in July 2006 and worked well and is already generating data on the spatial non-uniformity of dissipation in YBCO coated conductors.